Mobile Tracking Based on Area Partitioning

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Abstract: In the microcell- or picocell-based system the frequent movements of the mobile bring about excessive traffics into the networks. A mobile location estimation mechanism can facilitate both efficient resource allocation and better QoS provisioning through handoff optimization. Existing location estimation schemes consider only LOS model and have poor performance in presence of multi-path and shadowing. In this paper we study a novel scheme which can increase estimation accuracy by considering NLOS environment

1. Introduction

The major problem in the microcell or picocell-based mobile communication networks is the frequent movements of the mobile terminal or host which bring about excessive traffics into the networks. A mobile location estimation mechanism can facilitate efficient resource allocation and better QoS provisioning through handoff optimization. It can also reduce paging messages. Moreover it may be used in other new applications such as the emergency call for disaster recovery. It will have viable roles in the communication networks of the next generation.

In Reference [1] the estimation was done based on the signal strength received at the multi-beam antenna of the base station in the multi-path environment and the angle of its arrival (AOA). The AOA is measured under the assumption that the signal is in line of sight (LOS) but LOS signal may not be received in the area such as the microcell where reflections and diffractions occur due to crowded buildings. In this situation the estimation is done based on AOA of the reflected signal, if it is the strongest, and therefore the location estimated differs greatly from the real one. The time of arrival (TOA) of the signal from the mobile to neighboring base stations are used in Reference [2], but this scheme is not suitable for the microcellular environment like AOA scheme as it also assumes LOS environment. Reference [3] utilized the time difference of arrival (TDOA) of signals from two base stations. Recently TOA scheme and TDOA scheme are considered for IS-95B where PN code of CDMA system can be used for the location estimation. The above-mentioned schemes such as AOA, TOA and TDOA have problems as follows.

- These schemes assume that the cellular system consist of LOS areas. They get good results only under this assumption.
- In the microcellular environment such as IMT-2000, Non-Line of Sight (NLOS) areas exist mostly which are affected by specific reflections and diffractions. In this situation these schemes have great errors in estimation.
- In the microcellular environment the points of the same average signal strength form not the circular but the distorted contour. These schemes ignore the fact that the propagation rule is affected by many parameters.
- They rely only on the information related to radio signal such as the signal strength. Their accuracies are affected by short-term fading, shadowing and diffraction.

In this paper we propose novel location estimation schemes which can account for NLOS environments. Our schemes divide a cell into many blocks based on the signal strength, and then estimate in stepwise the optimal block where the mobile locates. This paper is organized as follows. Section II describes the signal measurement and the location definition for our system. Using the concepts described in Section II, three estimation schemes are proposed in Section III. Simulation environment and results are shown in Section IV in order to compare our schemes with each other. Finally the concluding remarks are given in Section V.

2. Location Definition

2.1 Signal Measurement

The signal level $r(t)$ received by the mobile from the station is given by Equation (1).

$$r(t) = p(t) \times f(t) \quad (1)$$

$p(t)$ indicates the local mean of path loss and shadowing in the signal power of pilot channel received by the mobile, and it has the log-normal distribution. $f(t)$ indicates the signal component of multi-path fading and has Rayleigh distribution or Rician distribution. The signal component of multi-path fading can be eliminated by the low pass filter or time-averaging. We consider log-normal fading and path-loss only [4]. Therefore the distribution of the signal received at the mobile is given by Equation (2).

$$p_A(d) = k_1 - k_2 \times \log(d) + u(t)$$
$$p_B(d) = k_1 - k_2 \times \log(D-d) + \upsilon(t) \quad (2)$$

In Equation (2) D indicates the distance between two base stations, and d the distance between the base station A and the mobile. k_1 is proportional to the transmission power of the station and k_2 has the offset value depending on the radio propagation environment. Two random signals $u(t)$, $\upsilon(t)$ which indicate the power distributions of signals received at the distance d from the station A and from the station B respectively have i.i.d (identical independent distribution) with Gaussian distribution of $N(\mu(d),\sigma)$. In our study the signal attenuation in NLOS environment is estimated based the distance in LOS model, and this result is reflected in the block object information. The changes in the LOS and NLOS environment are depicted by k_2.

The received signal strength changes arbitrarily at a place and it cannot be accurately defined with a single measurement. Therefore it is desirable to define the signal strength at a place as the average of values measured several times in a fixed interval. The strengths of pilot signal are measured repeatedly, the average of these values is calculated by Equation (3) and it is defined as the final estimated value. In this equation each *PSS* is the signal strength transmitted from the base station to the mobile at the time interval t_s (sampling interval) which is set by the timer. The average of *N* sample values is calculated for estimation. The average signal strength PSS_{ea} is given by the expression below [5].

$$PSS_{ea}(t_o + t_s) = \frac{1}{N}\sum_{i=0}^{N-1} PSS(t_0 - i \times t_s) \qquad (3)$$

2.2 Defining Location

The location of a mobile within a cell can be defined by dividing each cell into sectors, tracks and blocks and relating these to the signal level received by it at that point. It is done automatically in three phases of sector definition, track definition and block definition. Then the location definition database is constructed with these results. They are performed at the system initialization before executing the location estimation.

2.2.1 Sector Definition

The sector definition phase divides a cell into six sectors and assigns a sector number to the blocks belonging to each respective sector as shown in Figure 2.

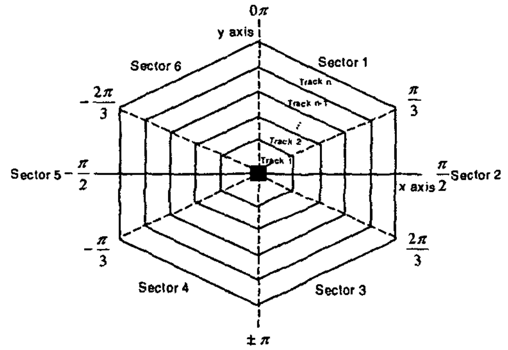

Figure 2. Dividing a cell into sectors and tracks

All blocks belonging to the same sector have the same sector number. In order to identify which blocks belong to which sector, the direction information of the vector is used which shows the direction of a block from the origin of the base station.

The sector definition procedure is summarized as follows.

a. Divide a cell into six sectors of a size.

b. Assign an angle for each sector at the interval of $\pi / 3$ respectively.

c. Compare the direction information of a block with the angle of each sector and determine which sector it belongs to.

d. Assign the corresponding sector number to each block

2.2.2 Track Definition

The track definition phase divides each sector into tracks, and assigns a track number to the blocks belonging to each respective track as shown in Figure 2. This definition phase can be described with two different algorithms depending on LOS model and NLOS model. Each cell is divided into n tracks with each track classified by PSS threshold as shown in Figure 3.

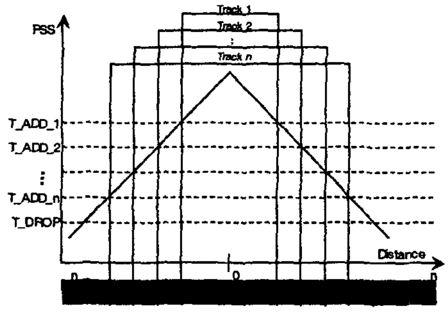

Figure 3. Track definition with PSS

The following algorithm summarizes the track definition procedure for LOS model.

a. Select each threshold considering PSS.

b. In order to map the signal strength onto the direction information, determine the distance function for each threshold with Equation (2).

c. Classify tracks using the distance function.

d. Assign the same track number and the PSS threshold to all blocks which belong to the same track.

But the above algorithm for LOS is not sufficient in the environment where blocks have a building or a hill. The boundary line for identifying each track of the same signal strength is severely distorted due to shadowing and diffraction. Further refinement with NLOS data is required as shown below.

a. Identify tracks by above LOS algorithm.

b. From blocks belonging to the same track, select blocks which need NLOS offset.

c. Assign NLOS offset, k_2, of Equation (2) to the blocks selected.

d. Find the difference between k_2 and PSS threshold which is determined by LOS.

e. Define new tracks by using the above difference as a new PSS.

2.2.3 Block Definition

In the block definition phase a block number is assigned to each block as shown in Figure 4. In order to indicate the location of each block within a cell, we use the vector data which is obtained by converting the rectangular coordinate of the block to the polar coordinate with the origin of the base station. Each vector has the information on a distance and an angle.

Also, in order to include the information about the path, we can incorporate the concept of "a node" or "an edge" into each block. If the mobile moves along the path (from A to B), the vector data indicates the location of the block which the mobile pass through within the cell, the node the point where the left or the right turn is made, and the edge the road within the cell. In order to represent the location of a block relative to the base station, 2-dimensional vector (d, a) is assigned to each block.

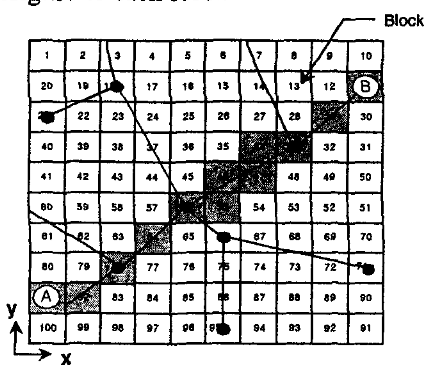

Figure 4. Identifying the block using the vector.

The collection of block information is called the *block object*. The *block object* contains the following information: the sector number, the track number, the block number, the vector data (d, a), the maximum and the minimum value of average PSS for the LOS block, the compensated value for the NLOS block and a bit for indicating "node" or "edge", etc.

3. Area Partitioning Based Estimation scheme

This scheme estimates the optimal block at which the mobile locates, utilizing the signal strength measurement in Section 2.1 and the location definition database which is constructed as described in Section 2.2. This scheme is implemented as an estimator into the base station. The estimator is started with the timer. And then the estimation is performed sequentially in three steps: sector estimation, track estimation and finally block estimation.

3.1 Sector Estimation

The sector estimation, the first step of the location estimation, is done in the following procedure.

A. All the neighboring base stations transmit pilot signals periodically.

B. The demodulator of the mobile measures PSS s of neighboring base stations.

C. The mobile sends PSMM (Pilot Strength Measurement Message) to the base station.

D. The estimator in the base station compares the received strengths of the pilot channels with each other and chooses the sector neighboring to the base station of the greatest signal strength as the sector at which the mobile locates.

E. Select all blocks with the same number of the above sector for the next step. These blocks can be selected by examining the sector number in the block object information.

$$\{B_k\}_1^{N_s} = \bigcap_{i=1}^{N} S \qquad (4)$$

where N is the total number of blocks, S the sector number estimated, N_s the number of all blocks selected in this estimation and B_k the block number.

3.2 Track Estimation

Using the sector of blocks selected in the sector estimation, the track estimation, the second step of the location estimation, estimates the track of blocks at one of which the mobile locates. It is done in the following procedure.

A. The base station transmits the pilot signal periodically.

B. The demodulator of the mobile measures the signal strength of the pilot channel of the base station in which it is.

C. The mobile sends PSMM to the base station.

D. The estimator estimates the track using the LOS algorithm and the NLOS compensated value.

E. The blocks belonging to the track estimated above are selected for the next step. This selection can be done by examining the track number in the block object information.

$$\{B_k\}_1^{N_T} = \bigcap_{i=1}^{N_s} T \qquad (5)$$

where N_s is the number of blocks selected in the sector estimation step, T the track number estimated, N_T the number of blocks selected in the track estimation and B_k the block number.

3.3 Block Estimation

Using the track of blocks selected in the track estimation, the block estimation, the last step of the location estimation, estimates the optimal block at which the mobile locates. It is done in the following procedure.

A. All neighboring base stations transmit the pilot signals periodically.

B. The demodulator of the mobile measures the signal strengths of the neighboring base stations.

C. The mobile sends PSMM to the base station.

D. The estimator calculates the delay difference between two signals by comparing PSS s of two base stations. Using this delay difference, it estimates the difference between the distance to one base station and the distance to another one.

E. From this difference of distances, the optimal block is estimated by the following procedures.

a. In order to figure out the relative location of the blocks estimated in the track estimation step, the serial numbers are assigned to these blocks.

b. The difference of two distances is mapped onto the block location using Equation (6).

$$B_l = PSS_{|A-B|}(d) / L \qquad (6)$$

where B_l is the relative location of the block, $PSS_{|A-B|}(d)$ the difference between the distance from base station A to the mobile and the distance from the base station B to the mobile, and L the length of a side of the block.

c. The temporary serial number and the block number are assigned using the block decision expression summarized in Table 1. In this estimation more than one block may be selected as optimal because PSS received at the mobile may be the same as the thresholds of two blocks if the mobile is at the crossing area of blocks.

Table 1. Block Decision Expression.

n_B	B_k	Signal strength		
		$PSS_A > PSS_B$	$PSS_A < PSS_B$	$PSS_A = PSS_B$
Odd	$B_k = n$	$(n_B+1)/2-n$	$(n_B+1)/2+n$	$(n_B+1)/2$
Even	$B_k = n$	$n_B/2-n$	$(n_B+1)/2+n$	$n_B/2$, $n_B/2+1$

4. Performance Evaluation

In our study we assume that the low-speed mobiles, the pedestrian, occupy 60% of the total population in the cell and the high-speed mobiles, the vehicles, 40%. The moving velocity is assumed to have the uniform distribution. The walking speed of the pedestrian is 0~5 Km/hr, the speed of the vehicles 10~100 Km/hr. The speed is assumed to be constant during walking or driving. Each block is a square and its side is assumed to have the length of n m. We consider the following simulation parameters regarding the received signal strength. The mean signal attenuation by the path-loss is proportional to 3.5 times the propagation distance, and the shadowing has the log-normal distribution with the standard deviation of $\sigma = 6dB$. The value of received signal strength less than $-16\ dB$ is regarded as the error, which is therefore excluded from the calculation.

According to the simulation results, we found that most of estimation errors occur when mobiles pass through sector and zone boundary lines or in the curved path. Estimation errors for the low speed mobile are mostly observed while it is moving through the curved path. On the other hand those for the high speed mobile are observed when it is moving through either the sector boundary lines or the curved path.

Figure 5 shows the estimation result for the situation where the mobile moves along straight or curved sector boundary area. In this figure the horizontal and vertical axes represent the relative location of the area observed and the path generated in this simulation. The left or right turn causes the abrupt signal distortions, but their effects on the estimation can be compensated by using NLOS algorithm for the boundary line which is severely distorted due to shadowing and diffraction.

Figure 6 shows the estimation rate or accuracy depending on the mobile speed and block size. The estimation rate increases rapidly as the mobile speed gets lower or the block size larger. The quality of those estimates is improved because our scheme estimates in stepwise the optimal block where the mobile locates, utililzing information on the signal value refined from LOS and NLOS algorithm.

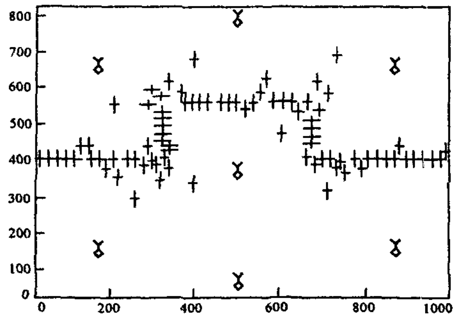

Figure 5. The estimation results on the move

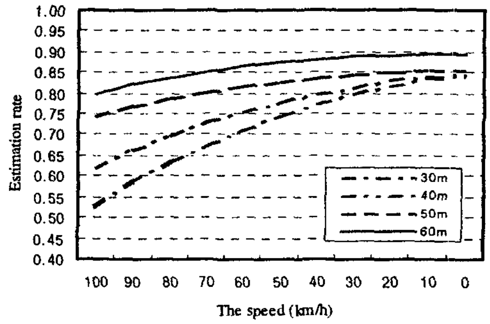

Figure 6. The estimation accuracy versus the speed

5. Conclusion

In this study, we proposed a Area Partitioning based on three step location estimations which can determine the mobile position by gradually reducing the area of the mobile position. We have clarified that our scheme increases the estimation rate in case of the mobile moves along boundary area. Further, we have showed that proposed scheme was little affected by the increased mobile speed or the decreased block size. Futher researches are required on their implementation and applications to the handoff and channel allocation strategies.

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